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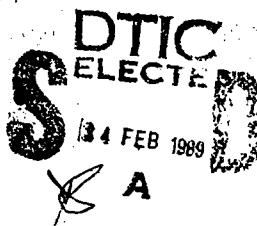
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DEVELOPMENT AND VALIDATION OF MEASUREMENT TECHNIQUES OF
TRANSMITTANCE OF THERMAL CONTRAST UTILIZING EXISTING IR IMAGERS

FINAL REPORT

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EUROPEAN RESEARCH OFFICE
UNITED STATES ARMY
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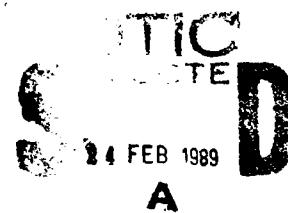
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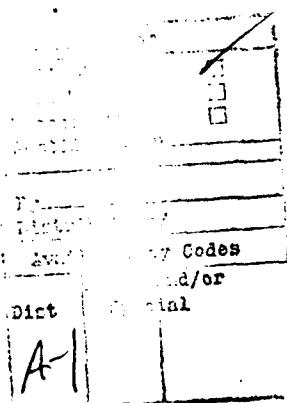
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ABSTRACT

This work describes a new technique used to measure the transmittance of IR contrast of thermal targets. The advantage of this technique is that it utilizes existing thermal imagers and does not require additional equipment in the field. The technique was tested with an AGA 780 Thermovision camera operating in the 8-13 micron spectral region, on the contrast of a thermal target as it "propagates" through smoke. An excellent agreement between theory and the experimental results was obtained.

1) INTRODUCTION

In our second interim report (R.A.A./87-140 from June 1987) we presented the results of a laboratory experiment in which the degradation of the intrinsic contrast of a 3-bar target in the presence of an oil-smoke obscurant, was measured by the use of an AGA 780 Thermovision camera. In this report we present the results of the measurements of the transmittance of the contrast of an electrically heated thermal target through a HC smoke screen. The IR measurements were made in the 8-13 micron spectral range and were compared to the visible contrast of the target. The calculation of the transmittance of the contrast were made according to the theory presented in the second interim report and were validated according to the nature of the obscurant which was a cold smoke.

The advantage of this method in comparison to the method of Atmospheric Transmittance Large-area Analysis System (ATLAS) will be discussed especially for the cases where the obscurant is a hot smoke.

2) THEORY

As was explained in the second interim report, $C(0)$ - the intrinsic contrast between a target and its background (which is the contrast in the target plane) can be expressed as

$$(1) \quad C(0) = [L_t(0) - L_b(0)]/L_b(0)$$

where $L_t(0)$ and $L_b(0)$ are the radiances of the target and the background, respectively, integrated over the spectral region in which our IR imaging system is operating. The units of L are usually mWatt/cm².str. As the distance s between the imaging system and the target is increased, the definition of the contrast remains the same

$$(2) \quad C(s) = [L_t(s) - L_b(s)]/L_b(s)$$

but its value changes. The contrast transmittance is defined as

$$(3) \quad T_c(s) = C(s)/C(0)$$

Since the radiance of the target and, consequently, the intrinsic contrast are not always available, the value of the contrast transmittance can be

calculated from the value of the total radiance that reaches the imaging system from the target after being attenuated by the path transmittance $\tau(s)$:

$$(4) \quad L_t(s) = L_t(0) \cdot \tau(s) + L_p(s)$$

where $L_p(s)$ is the path radiance. A similar expression holds for the total radiance that reaches the imaging system from the background. From Eqs. (4) and (2) the contrast transmittance can be expressed as

$$(5) \quad T_c(s) = 1/[1 + F(s)]$$

where $F(s) = L_p(s)/[L_b(0) \cdot \tau(s)]$. It should be noted that if the path radiance is zero the contrast transmittance will be equal to unity. However, under normal conditions, the optical path absorbs the radiance of the target and, as an absorber, it emits according to its temperature and emissivity. Under these conditions, where the temperature of the optical path is equivalent to that of the background and the optical path does not scatter radiation from another source (the sun, for example) into the field-of-view (FOV) of the imaging system, then it can be shown that $T_c(s) = \tau(s)$. However, under normal conditions these requirements are not satisfied, especially when the obscurant in the optical path (the smoke) is hotter than the rest of the optical path between the imaging system and the target, or when the obscurant is scattering sunlight (mainly in the visible).

3) EXPERIMENTAL SET-UP

A special thermal target was used in the field experiment. The target is composed from four rows of seven electrically heated thermal elements, and four rows which are left at ambient temperature. Each thermal element is 34 x 34 cm. The overall dimension of the target is 2.4 x 2.3 m. The maximum input power of this target is 1500 watt. This power can produce a maximum temperature difference of 20°C between the heated elements and those that are left at ambient temperature. The wind speed has a crucial effect on this temperature difference.

This target was placed 44.5 m from the AGA 780 Thermovision camera that operated in the spectral region 7.8-13.2 micron. A 3.5 x 3.5 degree lens was used in this test. Hence, the total field-of-view (FOV) of the camera was 2.7 x 2.7 m at the target plane. The video signal of the camera which is

expressed in IU (Isothermal Units) is calibrated against the radiance (in Watts/cm².str) of a standard black-body. This calibration is used to calculate the radiance of the target in the target plane for clear atmosphere (without smoke) by the use of a special computer program that takes into account the self-radiance and the attenuation of this atmosphere. Consequently, the net effect of the smoke can be calculated according to its attenuation and path radiance, as was explained in section 2.

A hot-water black-body was placed at the bottom right end of the thermal target as shown in Fig 1. The temperature of the water was stabilized to 40°C. Fig. 1 was made without any smoke obscuration with a regular video camera that was located near the thermal camera and had a FOV of 5 degrees. The clear-air infrared picture of the target is shown in Fig 2. Figures 3 and 4 show the effect of smoke on the visible and infrared contrast of the target, respectively. By comparing Figures 3 and 4, it is clear that though this smoke attenuated totally the visible contrast, it caused only a minor attenuation of the infrared contrast of the target. Consequently, a second measurement, but with thicker smoke, was made. Since during the second measurement the air temperature was higher and the wind speed was lower, also clear-air pictures of the target - in the visible and in the infrared - were made, as is shown in Figures 5 and 6, respectively. Figures 7 and 8 show the effect of this thicker smoke on the visible and infrared contrast.

4) CALCULATIONS AND RESULTS

The radiance (in mWatt/cm².str) of three rows (from the top) of heated elements of the thermal target was calculated from the thermal pictures and compared to the radiance of the adjacent rows which were at ambient temperature. This was done for the target as seen through clear atmosphere and the smoke-obscured target for the light smoke (Figs. 2 and 4) and for the thicker smoke (Figs. 6 and 8). The results of these calculations are shown in Table 1 in the first four columns.

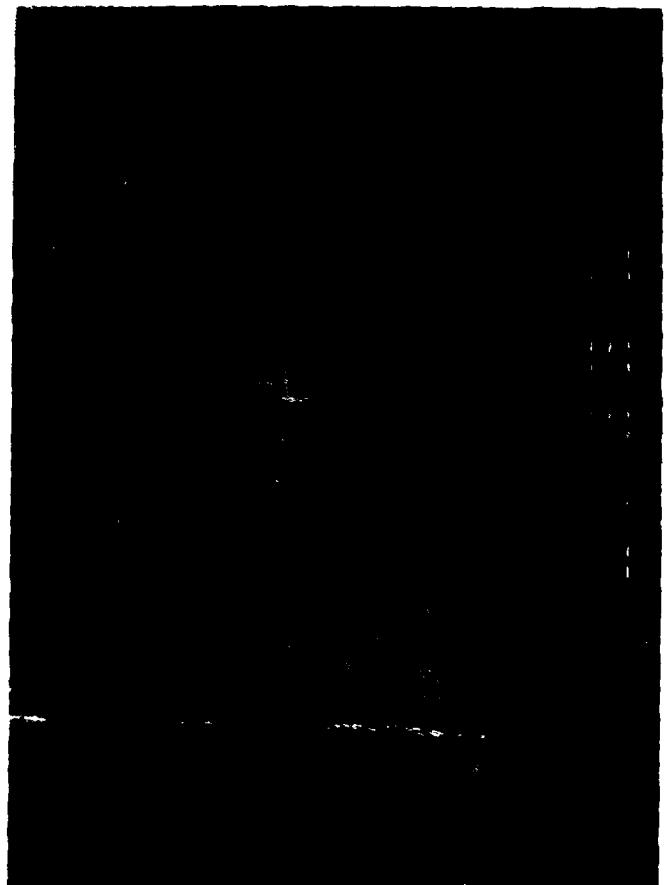


Fig. 1: The thermal target as seen in the visible just before the first measurement. At the bottom right end of the target we see the hot-water black-body. At the right of the target we see the collimated IR source used for the transmittance measurements.

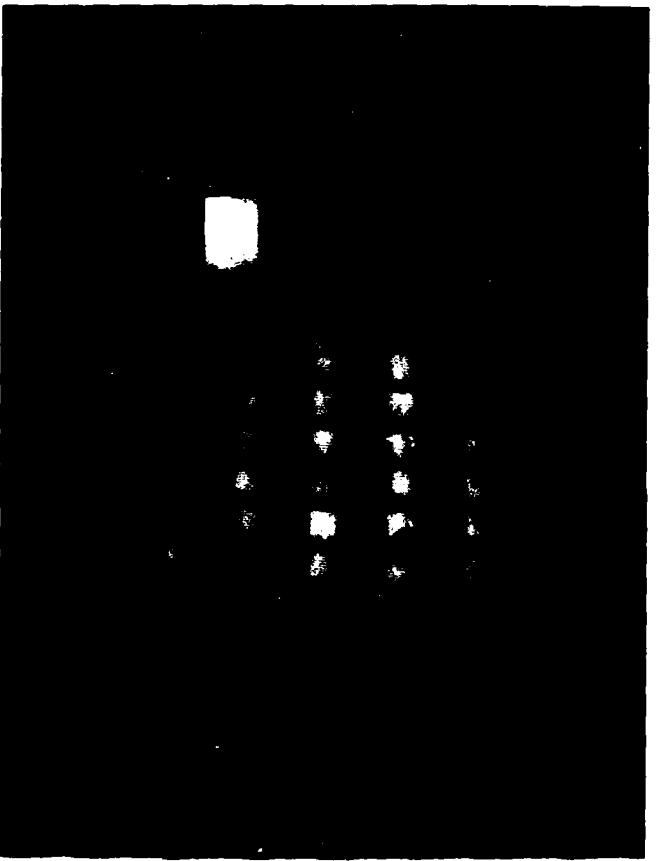


Fig. 2: The thermal target as seen in the infrared just before the first measurement.

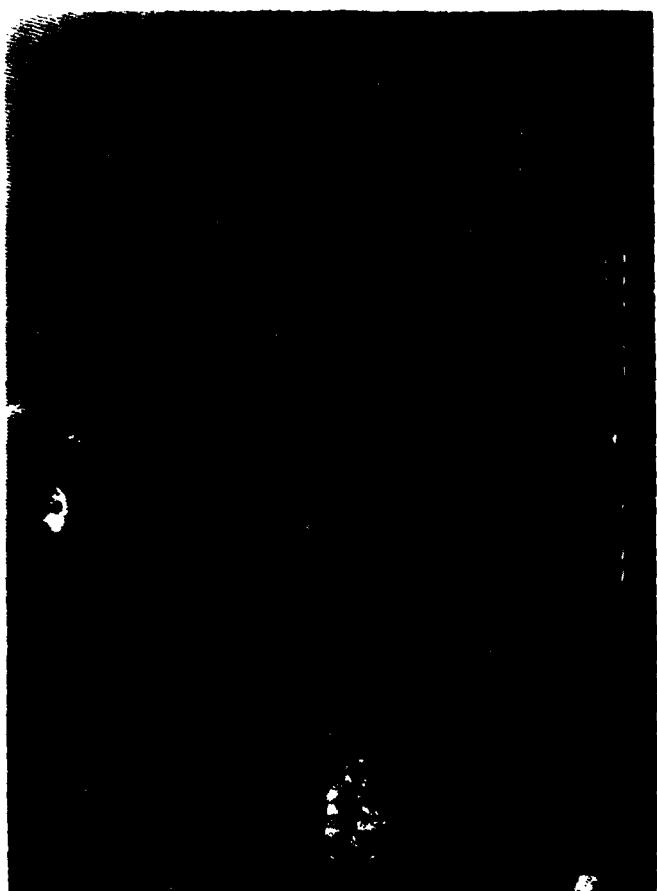
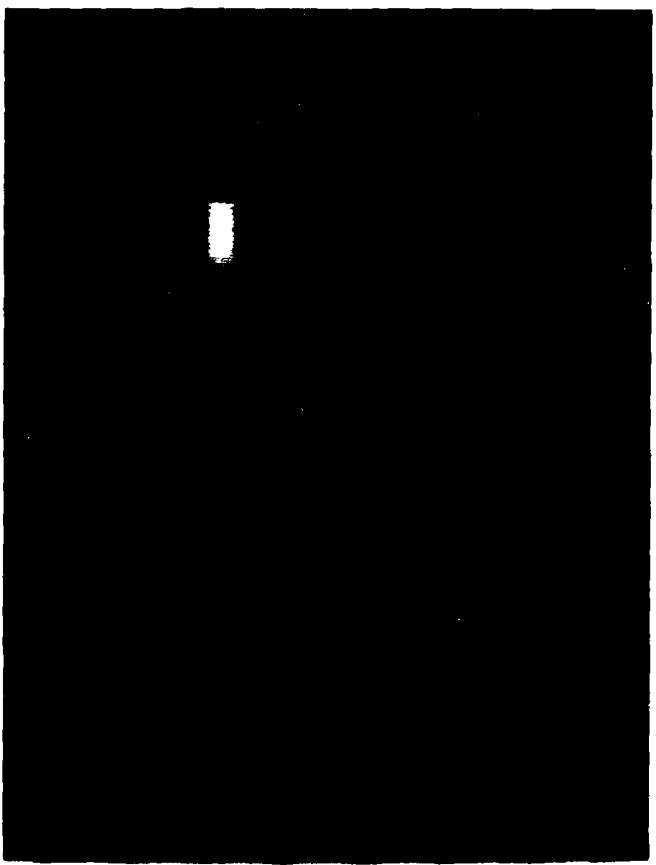


Fig. 3: The thermal target as seen in the visible during the first measurement.

Fig. 4: The thermal target as seen in the infrared during the first measurement.



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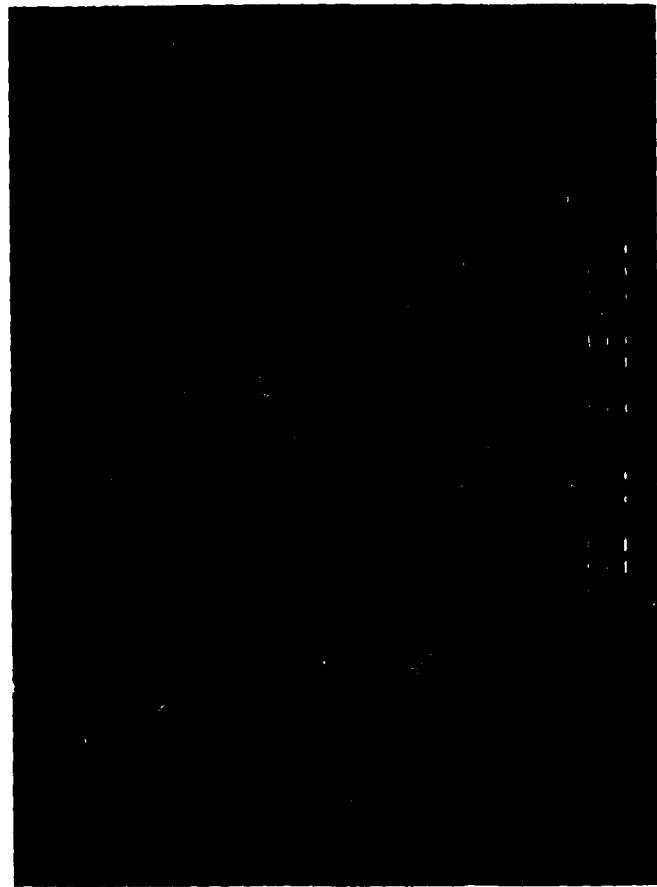


Fig. 5: The thermal target as seen in the visible before the second measurement.

Fig. 6: The thermal target as seen in the infrared before the second measurement.

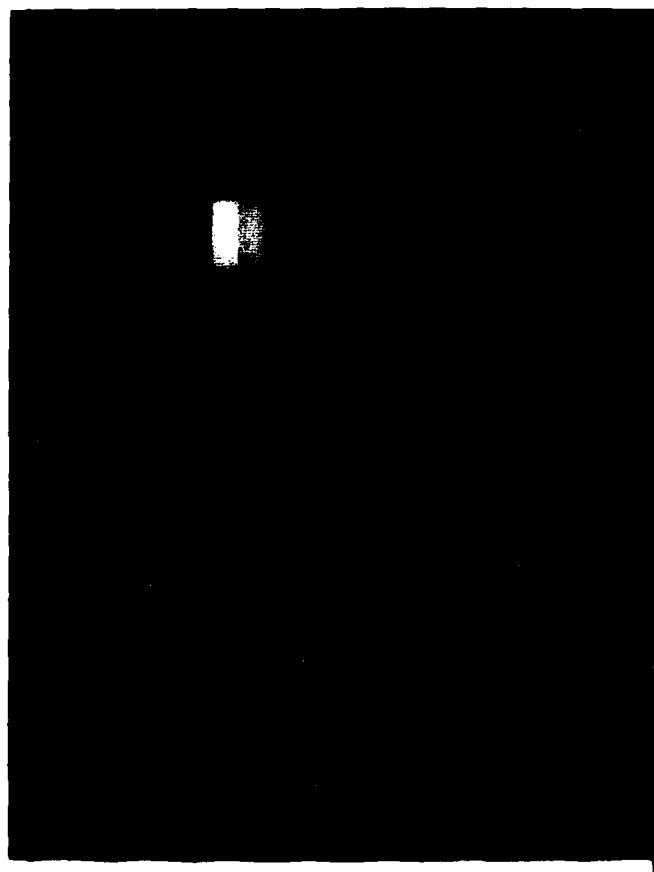
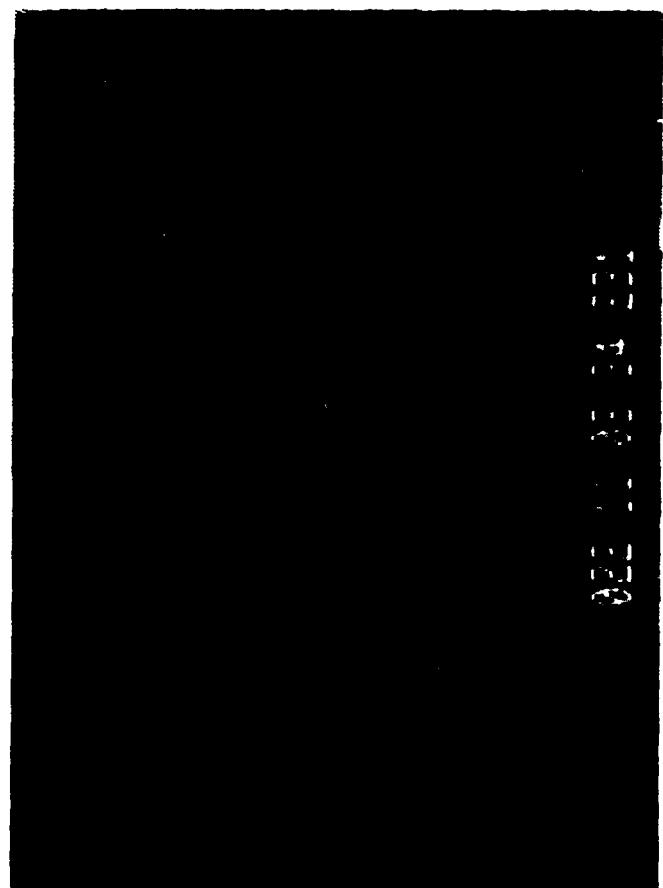


Fig. 7: The thermal target as seen in the visible during the second measurement.



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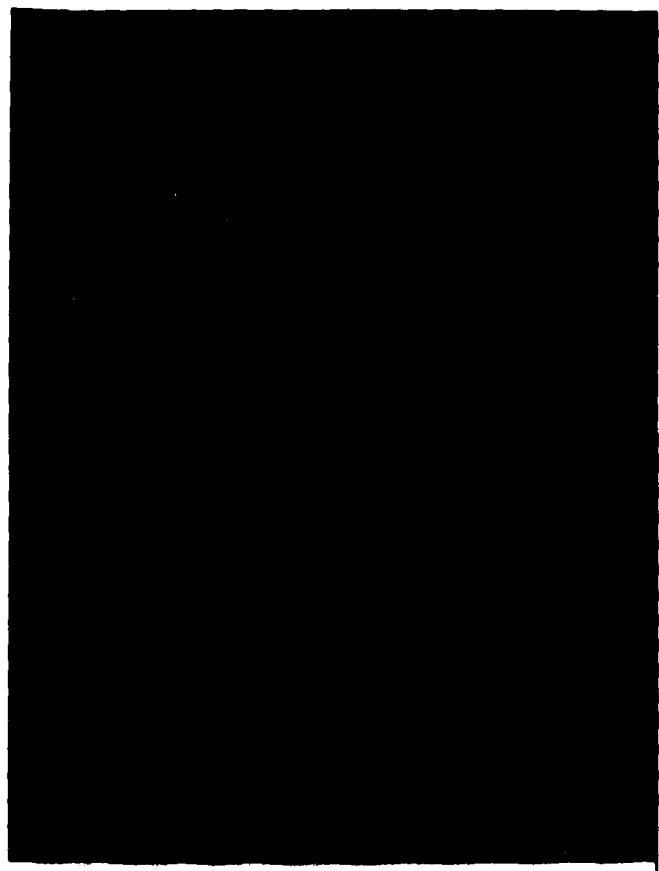


Fig. 8: The thermal target as seen in the infrared during the second measurement.

ROW	CLEAR-AIR		SMOKE-OBSCURED		$T_c(s)$	$\tau(s)$	$L_p(s)$	$e(s)$
	Heated	Ambient	Heated	Ambient				
1	5.75 (35.2°C)	4.53 (20.1°C)	5.50	4.48	0.827	0.821	0.777	0.171
2	5.78 (35.6°C)	4.55 (20.4°C)	5.56	4.51	0.846	0.841	0.696	0.154
3	5.76 (35.3°C)	4.54 (20.2°C)	5.52	4.51	0.823	0.823	0.777	0.171
<hr/>								
1	5.99 (38.0°C)	4.80 (23.6°C)	5.55	4.81	0.623	0.624	1.809	0.376
2	6.13 (39.6°C)	4.80 (23.6°C)	5.64	4.80	0.631	0.632	1.769	0.368
3	6.01 (38.2°C)	4.83 (24.0°C)	5.63	4.80	0.703	0.700	1.427	0.297
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Since these are the values of $L_t(0)$, $L_b(0)$, $L_t(s)$ and $L_b(s)$, respectively, the value of $T_c(s)$ was calculated from them according to Eqs. 3, 2, and 1, and is shown in the fifth column. From this value and Eq. 5, the value of $F(s)$ was calculated. In the expression for $F(s)$ and in Eq. 4 we have two unknown parameters: the attenuation of the path $\tau(s)$ and the path radiance $L_p(s)$. By solving these two equations, the two parameters are calculated as shown in the sixth and seventh columns. The path (smoke) temperature is assumed to be equal to the average temperature of the unheated rows of the target which are at the same ambient temperature as the background. From this temperature and the path radiance $L_p(s)$ the emissivity of the smoke is calculated and shown on the eighth column. This last assumption is not valid in the case of thermal smokes, as was mentioned in section 2. The average temperature is shown in parenthesis in the first and second columns. During the first experiment, just before the HC smoke was released, the temperatures of the heated and unheated (ambient) rows were carefully measured with an OMEGASCOPE model OS-2000A-S

infrared pyrometer. In the first test the readings were 44°C and 21°C (with fluctuations of approximately 1°C due to the moderate wind), compared with the AGA results of 35.4°C and 20.2°C . Here it is evident that the marked effect of the wind on the heated rows is due to the low thermal capacity of this target. The unheated rows do follow very well the ambient temperature of the wind.

Two conclusions can be drawn from these calculations:

- A) The identity between $T_c(s)$ and $\tau(s)$ indicates that the smoke is at ambient (air and background) temperature.
- B) The fact that the sum of $\tau(s)$ and $e(s)$ is almost unity confirm this indication.

5) DISCUSSION

During these measurements of contrast transmittance, a regular transmissometer was placed along the line-of-sight (LOS) of the AGA Thermovision camera. The collimated beam of the chopped IR source was not directed at the AGA camera to prevent saturation of the IR image at its location. The transmissometer operated at the same spectral bandwidth (7.8-13.2 micron) as the camera. Though the chopping frequency of the chopper was fairly high (400 Hz, approximately), there were temporal changes in the optical thickness of the smoke (that were caused by the wind), which had Fourier components that interfered with the measured values of the transmittance. The use of long time-constants (in the Lock-in Amplifiers) could cause incorrect transmittance results. Consequently, we could not verify our results of the path transmittance $\tau(s)$ against regular transmittance measurements. Nevertheless, we hope to do this in future experiments.

When we compare our method with the ATLAS method we see that both methods do require stable thermal targets that do not vary in their temperature as a result of windy conditions. This is a natural requirement, since if there are (wind-induced) temperature changes in the targets - there is no point in any analysis of the effect of smoke on the their thermal contrast.

The main difference between our method and the ATLAS method is that our method does not require a transmissometer in the experimental set-up whereas in the ATLAS method it plays a central role. However, it should be noted that the

curve-fitting between the measured grey levels of the "point" of the IR source and the transmissometer data is possible only if:

- A) The gain and level of the video signal (contrast and brightness) are always kept constant during the measurement (no AGC!).
- B) The video signal of the transmissometer "point" is not saturated while the video signal of the targets and background is kept well above zero.

The most serious problem occurs in the ATLAS method when hot or thermal smoke is used; the transmissometer cannot measure the contribution of the path radiance of the smoke and, consequently, there is no possible way to make the curve-fitting between the grey level of the video signal and the transmissometer data. It should be noted that the hotter the smoke the larger will be its path radiance and the smaller will be its contrast transmittance (see Eq. 5). As a matter of fact the difference between the effects of a regular smoke and a thermal smoke on the thermal contrast of a target is like the difference between the effect of a regular smoke in the IR region to its effect in the visible region where the role of path radiance is substituted by the role of scattering of solar radiance, as can be seen in Figs. 3 and 7.

6) CONCLUSION

In conclusion we would like to state that since no obvious advantage is gained by using a transmissometer to derive smoke transmittance values, the direct contrast method is preferable; this method is both simpler and more reliable than the ATLAS method since it takes into account all atmospheric medium factors, and especially the path radiance, in the derivation of the results. Another advantage is that this method does not require a transmissometer in the FOV of the camera.

7) RECOMMENDATIONS

It seems to us that the problem of the evaluation of the contrast transmittance in the IR should be, because of its complexity, investigated by both methods using different kinds of smokes.

8) ACKNOWLEDGEMENTS

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